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Collapse of a coal loadout structure from fatigue caused by wind-induced vibration

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Abstract

This paper describes the collapse of a large coal loadout structure after one year of operation. The incident occurred on a calm day and without warning. The conclusion of the consultants for the designers and constructors was that there had been a severe overload. The opinion of the writer however, in acting for the owners, was that the failure was due to fatigue. After rebuilding of the structure, it was concluded that fatigue had occurred, being caused by wind-induced vibration, and the structure had to be modified further to provide direct support for the cantilevered portion of the structure that had collapsed. Wind tunnel testing confirmed the fatigue had been induced by vortex shedding and resonance in the structure. In the original design due consideration had not been given to such effects.

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Coal loadout structure; collapse; fatigue; wind-induced vibration

1. Introduction

A large (1800 t/h) coal loadout stage had been operating for approximately one year since construction in 1980 without apparent problems being noted. On a sunny afternoon towards the end of summer with negligible wind, the cantilevered section at the outer end collapsed suddenly without warning, putting the loadout stage out of commission and shutting off the supply of coal from the open pit mine to the rail line that transmitted the coal to a power station some distance away. The loadout stage was constructed from rectangular hollow steel sections and clad externally with corrugated steel panels.

The suspicion of the writer was that there had been a fatigue failure because of inadequate design margins for dynamic and periodic loading. Simplified fatigue analysis supported this proposition, further reinforced by the fact that the structure was operating below its rated maximum load conditions. Moreover it had been subjected to such loading on previous occasions without apparent problems. However, this was not the view of the designers and constructors who postulated an overload condition caused by possible buildup of coal on the conveyer and by plugging of the retractable coal chute with product.

2. Description of the Failure Event

Fig. 1 shows the coal loadout stage prior to the failure and Fig. 2 shows the failure of the cantilevered end section after the failure event. Fig. 3 illustrates the structure of the stage in greater detail.

The initial failure occurred at the welded connections between the diagonal members indicated in Fig. 3 and shown more clearly in Fig.4.

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Fig.1. Coal loadout stage in operation, transferring coal to hopper cars.

Fig.2. Head chute embedded in coal heap after failure of the structural members at the start of the cantilevered section of the loadout stage.

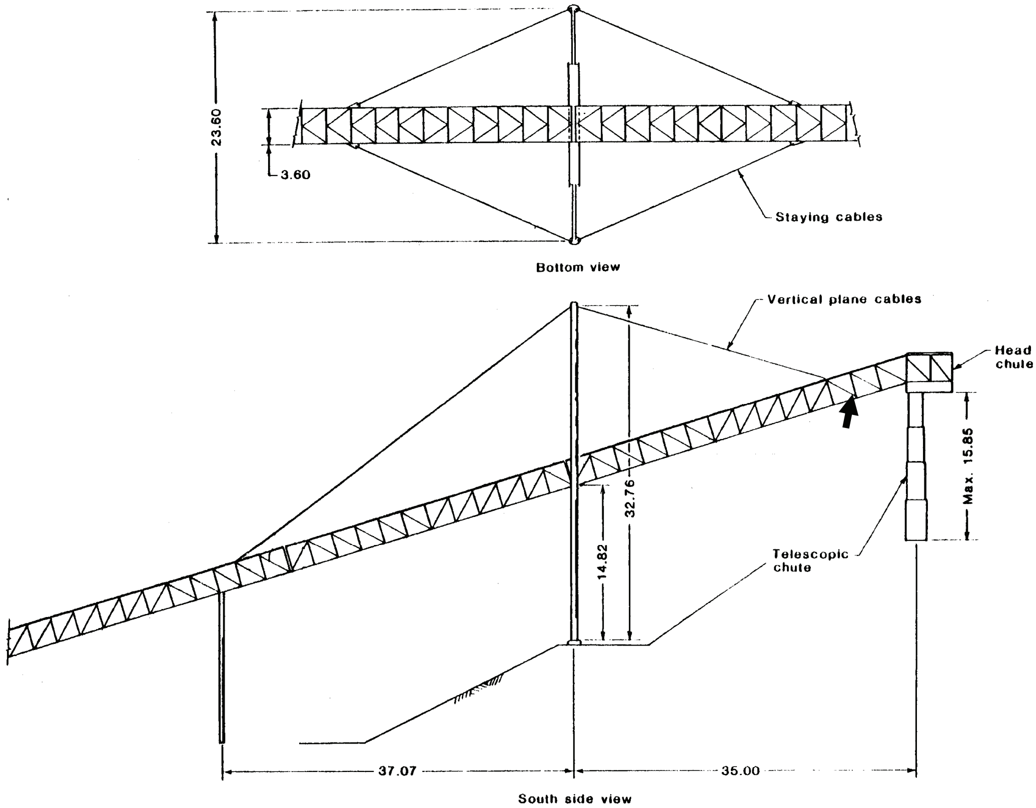

Fig 3. Schematic diagram of the structure of the loadout stage. The arrow indicates the joints where collapse started. The dimensions are shown in metres.

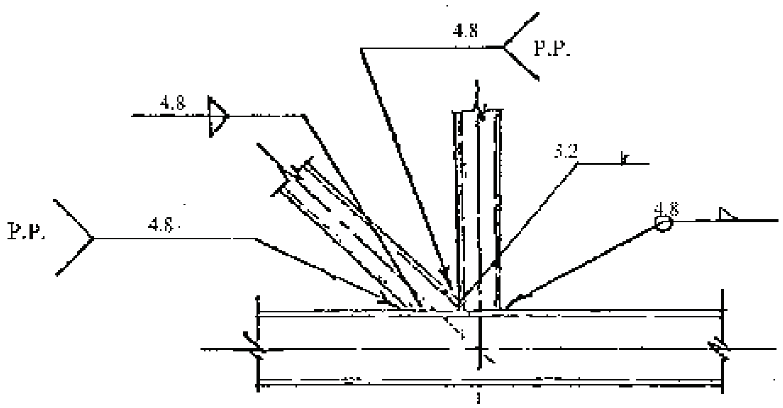

Fig. 4. Detail of the failed joint. Weld sizes are in mm.

3. Further Investigation

As already noted, the investigators for the design and construction parties to the case concluded that overload must have been caused by a combination of events producing a single large overload. The speculation was that this involved buildup of coal on the conveyor along the loadout stage; build-up of coal within the head; blocking of the chute; and side loading on this through being immersed in the coal heap. Even so, the loading on the members that fractured did not lead convincingly to the explanation being a satisfactory one.

It may be noted that the weld sizes were small (Fig. 3) and that joints were of the partial penetration type, not construction details that are appropriate for conditions in which high resistance to fatigue would be required.

The fracture surfaces were examined fully and it was observed that all consisted of ductile dimples, something which will be discussed later in the paper. It was agreed by all parties that the loads that would have been carried by the structure during normal operation would not have produced failure, although the design of the welded joints was certainly marginal and did not provide for what would be considered a normal factor of safety. On this basis the consultants for the designers and constructors concluded that overload was the cause of the failure and ruled out further consideration of fatigue as a possible cause.

The structure was rebuilt with more substantial connections and welds, together with precautions to prevent possible build-up of excess coal that could produce an overload condition.

As previously noted, the writer had been concerned from the outset that the failure could have been caused by fatigue, although the direct evidence for this was slight. However, subsequent discussions with the operators and examination of weather records brought to light information that, during a period when a strong crosswind accompanied by a rainstorm had occurred during the first year of operation of the original structure, vortices had been observed at the corners of the structure. Nevertheless, nobody had thought of the possible importance of these observations at the time, and only when such conditions occurred once more and such vortices were again observed, was the information brought forward.

Accordingly, testing was made of a model of the original structure in a low speed wind tunnel, and the result was that severe wind-induced vibration was observed, justifying the earlier speculation of fatigue as the probable cause of failure.

The one matter in which doubt over fatigue as the cause of failure was still being expressed, namely the absence of clear fatigue striations, could now be cleared up. The fracture surfaces corresponding to the joints at which the initial failures had occurred had a morphology of ductile dimples that were essentially aligned. As the mean stress in these regions was very high, a mechanism of fatigue by progressive incremental tensile tearing with each stress cycle was concluded to have occurred.

Subsequently the structure was modified further to eliminate the presence of the cantilevered section by provision of an A-frame straddling the head chute and coal heap, and supporting the head frame directly. As the structure was later scrapped, together with the distribution system involving the rail link, for economic reasons, the writer has been unable to provide a photograph of the modifications made for the final limited time of operation.

4. Conclusions

The importance of analyzing structures fully and of conducting testing of these when appropriate, has been demonstrated in situations where vibrational effects leading to possible resonance and potential failure by fatigue may occur.

The matter of fatigue under high mean stress, particularly in thin-walled members, has been noted, as the normally characteristic fatigue striations expected may not be detected, but instead progressive formation of ductile dimples may be produced.

The benefit of wind tunnel testing of models of structures in which resonant vibration may occur is emphasized. Clearly this should be done before a design is finalized and the structure built, where there is any uncertainty as to the long-term stability of such a structure.